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Were Global $M \geq 8.3$ Earthquake Time Intervals Random between 1900 and 2011?

by Tom Parsons and Eric L. Geist

Abstract The pattern of great earthquakes during the past ~100 yr raises questions whether large earthquake occurrence is linked across global distances, or whether temporal clustering can be attributed to random chance. Great-earthquake frequency during the past decade in particular has engendered media speculation of heightened global hazard. We therefore examine interevent distributions of Earth's largest earthquakes at one-year resolution, and calculate how compatible they are with a random-in-time Poisson process. We show, using synthetic catalogs, that the probability of any specific global interevent distribution happening is low, and that short-term clusters are the least repeatable features of a Poisson process. We examine the real catalog and find, just as expected from synthetic catalogs, that the least probable $M \geq 8.3$ earthquake intervals during the past 111 yr were the shortest ($t < 1$ yr) if a Poisson process is active (mean rate of 3.2%). When we study an $M \geq 8.3$ catalog with locally triggered events removed, we find a higher mean rate of 9.5% for 0–1 yr intervals, comparable to the value (11.1%) obtained for simulated catalogs drawn from random-in-time exponential distributions. We emphasize short interevent times here because they are the most obvious and have led to speculation about physical links among global earthquakes. We also find that comparison of the whole 111-yr observed $M \geq 8.3$ interevent distribution (including long quiescent periods) to a Poisson process is not significantly different than the same comparison made with synthetic catalogs. We therefore find no evidence that global great-earthquake occurrence is not a random-in-time Poisson process.

Introduction

We are curious whether clusters of great earthquakes in the 1960s and 2000s that bounded an intervening period of quiescence (Fig. 1) point to a physical process (Bufe and Perkins, 2005; Pollitz *et al.*, 1998), or whether these interevent times are consistent with a random-in-time Poisson process. A Poisson process is one in which events occur independently and with an exponential distribution of times between events. We therefore calculate the frequency that observed earthquake intervals came from an exponential distribution of the form $p(T) = \frac{1}{\mu}\exp(\frac{-T}{\mu})$ (where T is time, and μ is mean interevent time) because this function yields uniform probability (P) versus time for a given period (ΔT) as $P(T \leq \Delta T) = 1 - \exp(-\Delta T/\mu)$. Consistency with a Poisson process means that the global large-earthquake hazard is constant in time and, outside of local aftershock zones (Parsons and Velasco, 2011), not related to past events. Inconsistency at high confidence could be interpreted to imply a global seismic cycle, as Bufe and Perkins (2005) did.

The possibility that earthquakes communicate across global distances could revolutionize our concept of time-dependent worldwide hazard, but past study has yielded differing answers (Bufe and Perkins, 2005; Geist and Parsons, 2011; Michael, 2011; Shearer and Stark, 2012). In this paper, we focus on finding out how often the observed frequency of interevent times, discretized into one-year bins, could have occurred randomly. We examine these features closely because short-term clusters of high global activity get noticed by seismologists, the public, and the press (e.g., Barcott, 2011; Winchester, 2011), with all parties concerned about the possible heightened worldwide earthquake hazard.

$M \geq 8.3$ Earthquakes between 1900 and 2011

We extract $M \geq 8.3$ events from the 1900–1999 Centennial catalog (Engdahl and Villaseñor, 2002; Fig. 2), augmented for the period 2000–2011 with the Advanced National Seismic System (ANSS) and Global Seismograph Network (GSN) catalog (Table 1). The $M \geq 8.3$ level is well above the completeness threshold, and moment magnitudes have been calculated and compiled by Engdahl and Villaseñor (2002). Our lower magnitude of interest is arbitrarily chosen to some extent, but there are reasons why $M \geq 8.3$ turns out

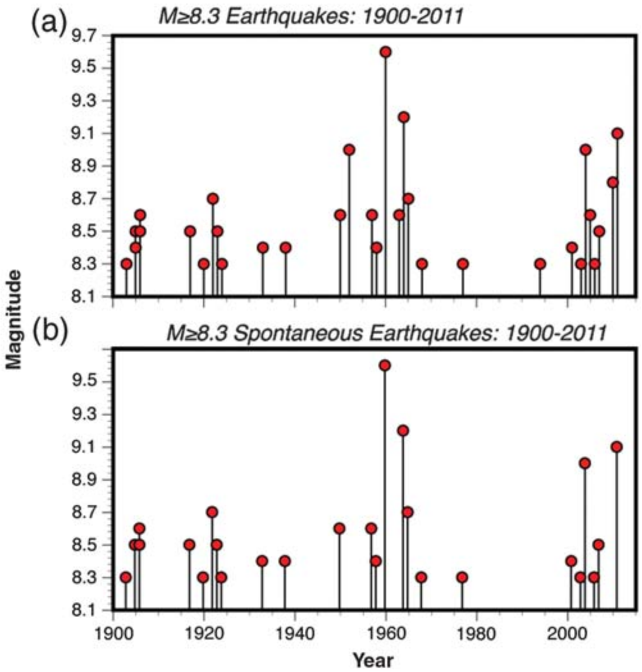

Figure 1. Graphical representation of the $M \geq 8.3$ earthquake catalog we use in this study (Engdahl and Villaseñor, 2002) augmented for the period 2000–2011 with the ANSS catalog. All event sizes are given as moment magnitudes. Clusters of events interspersed with quiescent periods are evident. (a) All catalog events are shown. (b) A catalog with likely aftershocks/triggered earthquakes removed is shown.

to be a good number both for catalog completeness and for identifying triggered events. Magnitude completeness is a very serious issue when assessing interevent time distributions, as we do in this paper. Even one missing event could completely alter the conclusions, particularly when it comes to studying long periods of quiescence (as can be seen in Fig. 1).

An important component to this study is identifying likely triggered earthquakes that have occurred through identified physical processes. This becomes increasingly difficult to do with lower magnitude thresholds and requires the use of declustering algorithms, which bring their own sources of significant uncertainty. With the $M \geq 8.3$ cutoff, we have the ability to assess each earthquake individually and can cite past studies where the interaction physics have been modeled. We identify likely nonspontaneous $M \geq 8.3$ events (Fig. 2) as those that have been directly associated with stress-change models (Chery *et al.*, 2001; Nalbant *et al.*, 2005; Stein *et al.*, 2010), or that fit empirical observations of aftershock characteristics in time and space (Parsons, 2002; Ruppert *et al.*, 2007). Where there is specific information about a possible $M \geq 8.3$ aftershock that is inconsistent with a known physical process, we do not remove it from the catalog, as in the case of the 2007 $M \geq 8.6$ Sunda earthquake (Wiseman and Bürgmann, 2011).

Fit of the Raw Catalog to Time-Dependent and Time-Independent Distributions

Simple statistical analyses can be performed on the catalog to determine whether it is consistent with a time-dependent process, a Poisson process, and/or with a cluster-type model. In particular, the distribution of interevent times can be compared to a lognormal distribution, an exponential distribution in the case of a Poisson process, or a gamma distribution that better accounts for aftershocks and triggered events (Corral, 2004; Hainzl *et al.*, 2006). We compare the empirical density function for $M \geq 8.3$ interevent times with the best-fit lognormal, exponential, and gamma distributions

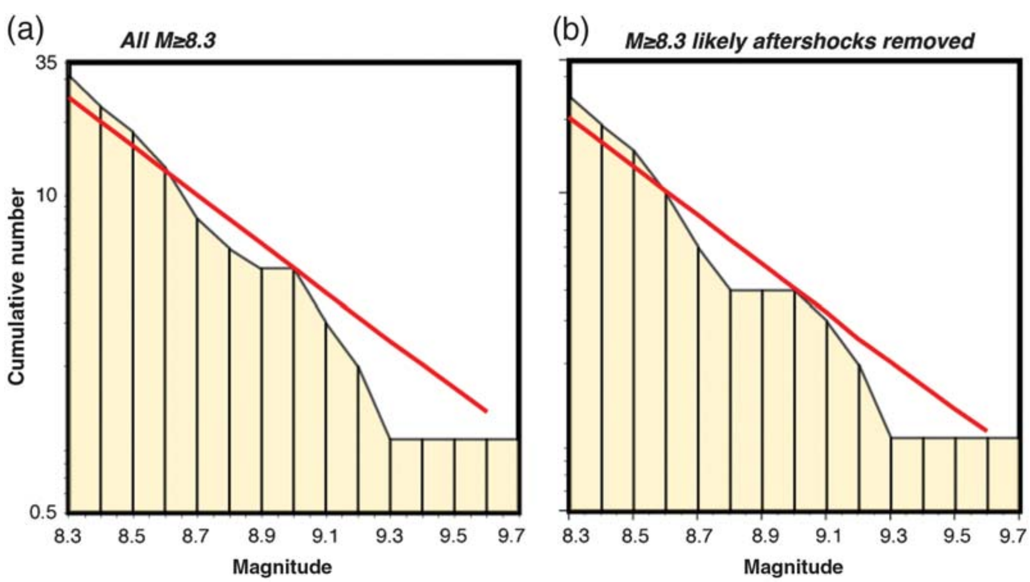

Figure 2. (a) The magnitude-frequency distribution of all catalog events (columns). (b) The magnitude-frequency distribution of a catalog with likely aftershocks/triggered earthquakes removed. The red lines are b-value = 1 slopes for reference.

using maximum likelihood estimation (Fig. 3). Because the distributions are similar, and because the lognormal and gamma distributions include an additional shape parameter, the Akaike information criterion (AIC) is lowest for the exponential distribution (138.6), increases to 140.2 for the gamma distribution, and is highest for the lognormal (141.6). The significance of the AIC difference between lognormal and the other distributions is difficult to judge, because they are not from the same family. However, if the AIC is used as a goodness-of-fit measure (e.g., Ogata, 1998), then the exponential distribution is the preferred statistical model for the interevent distribution of $M \geq 8.3$ events.

A Kolmogoroff–Smirnoff (K–S) test on global large earthquake interevent times for different magnitude cutoffs was performed on a declustered catalog by Michael (2011), who found that the exponential distribution cannot be rejected for large magnitude cutoffs ($M \geq 7.5$, 8.5, 9) at 95% confidence. We repeat these K–S calculations for the three distributions shown in Figure 3 and find that the null hypothesis of the data being distributed according to each of the three distributions cannot be rejected at the 5% significance level. Therefore the raw data are not sufficient to prove any of the common earthquake recurrence distribution families. This generalized approach shows that the overall interevent distribution can be fit in a number of ways but does not give us insight into how unusual specific features of great-earthquake clusters and gaps are relative to the possibility that they have happened by random chance. Further, we have not yet accounted for magnitude uncertainty.

Magnitude Uncertainty

Assembling post-1900 earthquake catalogs requires us to address uncertainties about earthquake size. Actual magnitudes might be higher or lower than the catalog values, and because a magnitude cutoff has to be applied in any analysis, interevent times will be affected. Magnitude is expressed on a logarithmic scale, meaning that a uniform plus or minus error estimate in magnitude units would systematically bias the implied moment (energy) upward. We instead convert reported catalog magnitudes to linear moment, apply Gaussian uncertainties centered on reported values, and then convert those distributions back to magnitudes (Fig. 4).

We use moment uncertainty distributions with coefficient of variation (COV, standard deviation divided by the mean) of 0.5 for earthquakes before 1950 and a COV of 0.2 for those after, which matches given magnitude uncertainty limits (Engdahl and Villaseñor, 2002) with logarithmic weighting. We draw 100 catalogs at random from possible magnitudes (Fig. 4) for cutoff thresholds between $M \geq 8.3$ and $M \geq 8.7$ and calculate interevent times for each draw, yielding a range of possible observed intervals for each one-year bin (the mean values from this exercise are shown in Fig. 5).

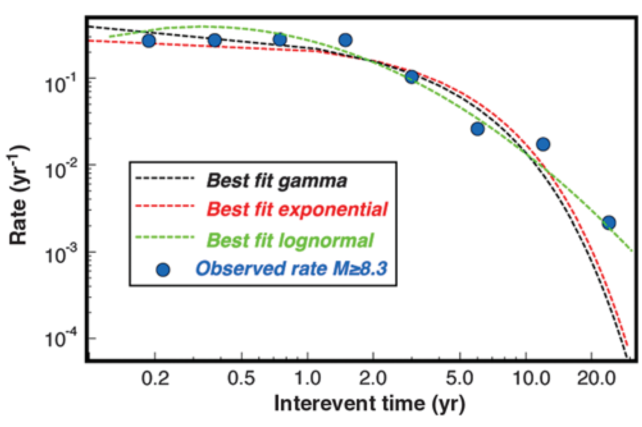

Figure 3. Density distribution of interevent times (years) for the $M \geq 8.3$ earthquake catalog. The dots show the empirical density function using exponential binning (Corral, 2004). The red dashed line shows the best-fit (using maximum likelihood estimation) exponential distribution, the black dashed line shows the best-fit gamma distribution, and the green dashed line shows the best-fit lognormal distribution.

Probability of a Given Number of Interevent Intervals in One-Year Bins Determined from Synthetic Catalogs

The global pattern of large earthquakes has long periods of quiescence interspersed with short-term clusters of events that are calculated to be unlikely outcomes from a Poisson

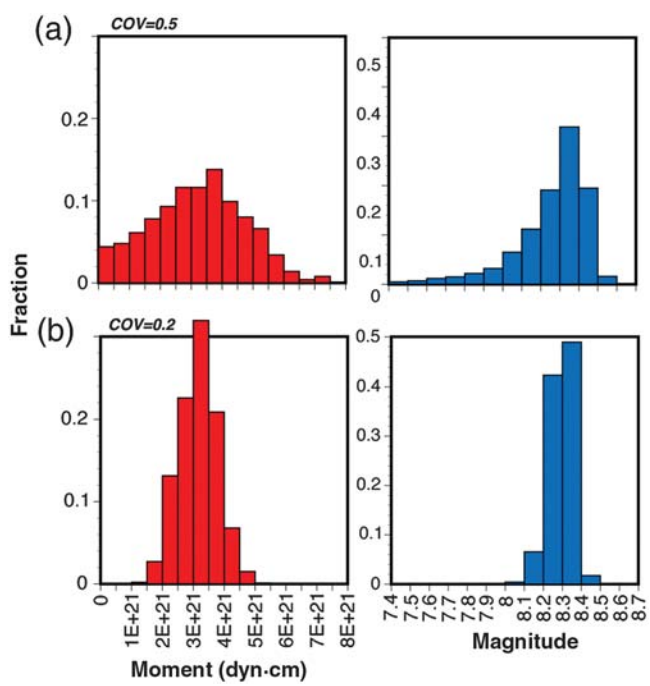

Figure 4. Magnitude uncertainty is addressed by applying a Gaussian distribution to the moment estimates (red columns) of each catalog earthquake. In these examples, the mean moment is derived from an M 8.3 earthquake. The resulting logarithmic magnitude uncertainty distributions are shown as blue columns. We apply in (a) a 0.5 COV to moment of pre 1950 events and in (b) a 0.2 COV to post 1950 earthquakes.

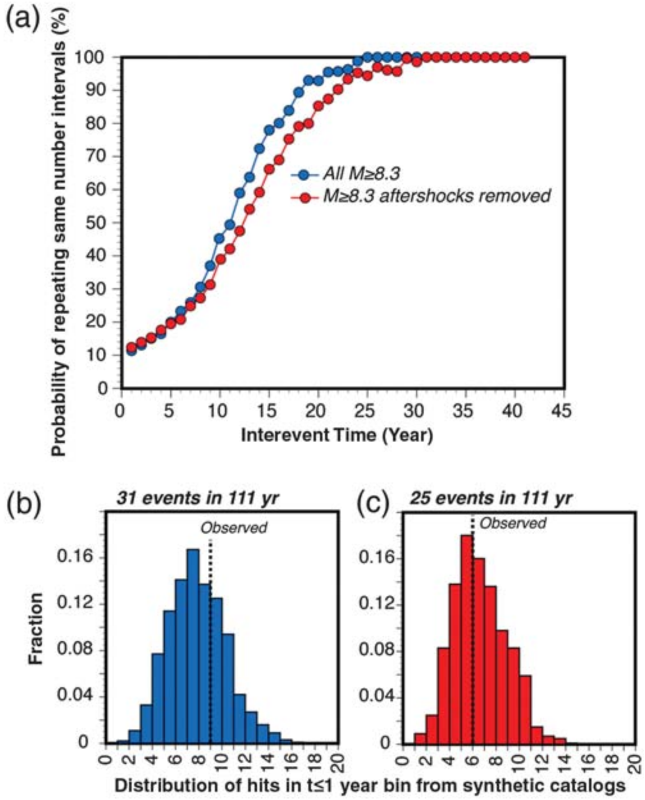

Figure 5. (a) The probability of the same number of intervals occurring in a 111 yr period if earthquakes occur randomly through a Poisson process as determined from 1000 synthetic catalogs drawn at random from exponential distributions. The blue curve shows values for all $M \geq 8.3$ events (31 in 111 yr), and the red curve shows the same information but intended to simulate the catalog with likely triggered earthquakes removed (25 events in 111 yr). The 0–1-yr interevent bin has the lowest probability of repeating at ~11%. (b) A histogram showing the distribution of the number of events (ranges from 1 to 15) happening at 0–1-yr intervals for 31 events in 111 yr from synthetic catalogs. (c) The same information as in (b) except for a simulation of the catalog with aftershocks removed.

process by Bufe and Perkins (2005). This is true, though any specific outcome is unlikely if earthquake occurrence is random. We show this by conducting a simple experiment; we create 1000 synthetic earthquake catalogs by drawing sets of 31 events at random from an exponential distribution of intervals (mean rate parameter found by dividing 31 events by 111 yr). We see no two interevent distributions out of 1000 that are exactly alike when the synthetic catalogs are discretized in one-year bins.

To get to the issue of specific observed features, we can narrow the focus to a particular attribute of the synthetic catalogs, for example the 0–1 yr interevent period, and count how many times a given number of intervals is seen in that bin (values from synthetic catalogs span a range from 1 to 15) (Fig. 5b, c). This just amounts to comparing each synthetic catalog of intervals to all the others. The average frequency that any number of intervals falls into the 0–1 yr bin is 11.1% of the 1000 synthetic catalogs, where any number refers to repeats of values from the entire 1-to-15 range. The percentage of synthetic catalogs that repeat the number of intervals in a given one-year bin can be thought of as the probability of a particular clustering behavior that might arise if 31 earthquakes occurred at random over a 111-yr period (or 25 in 111 yr if a catalog with aftershocks removed is considered). Generally, the probability of seeing a particular number of intervals increases with longer interevent times because most of them are zero in the synthetic catalogs (Fig. 5a). Further, the exponential distribution has the most weight at small values, therefore its histogram has more possible integer values in the short time bins, making them less likely to be repeated.

The results of this numerical experiment are useful because they provide a context to consider when we compare the observed record of $M \geq 8.3$ earthquakes over the past 111 yr to synthetic catalogs. For example, if we think the number of great earthquakes that has happened closely spaced in time (say, less than one year apart) is anomalous, we might take note that any number of events that have happened less than one year apart is unusual under a Poisson process. If great earthquakes are independent of one another, we would expect any given 111-yr period to display short-term ($t \leq 1$ yr) earthquake clustering that has only about an 11% chance of occurring.

Matching Observed Features in the Global Interevent Distribution to Exponential (Random-in-Time) Distributions

The exercise shown in Figure 3, and those conducted by Michael (2011), imply that the observed record of great earthquakes is insufficiently persuasive to rule out representative functions of the interevent distribution families thought to underlie earthquake occurrence. However, we remain curious about how unusual specific features of the past 111 yr of $M \geq 8.3$ earthquakes are, particularly short-term clusters like the period from 2000 to 2011. So, to address public concerns about apparent large earthquake clustering (e.g., Barcott, 2011; Winchester, 2011), we attempt to replicate these features—observation and nonobservation of interevent times at one-year resolution—of the global interevent distribution with synthetic catalogs generated through a Poisson process, while assessing the impact of magnitude uncertainty.

We focus on the exponential distribution because it can represent a null hypothesis of independent earthquake timing when event intervals are drawn from it at random (we test the observed catalog for independence in a later section). We calculate the rates that observed intervals within one-year bins match a Poisson process by comparing with 1000 interevent distributions from synthetic catalogs made randomly from exponential distributions (Fig. 6). The idea is that, because a 111-yr period is relatively short compared with recurrence intervals of great earthquakes, we can examine many synthetic catalogs to look for patterns that replicate observations and gain some insight as to how common observed features are, such as temporal earthquake clustering. This is similar to the general experiment described previously, but now we compare directly to observed values. Multiple synthetic catalogs give us a way to assess the impact of the small sampling.

Construction of Synthetic Catalogs and Method of Comparison with Observations

A group of 1000 synthetic catalogs is made for each of the 100 potentially observed catalogs. Each of the 100 catalogs is a potential observation because of magnitude uncertainty. This means that some events can drop under a given lower magnitude threshold because, in some of the 100 realizations, they can end up with too small of a magnitude to be included. Therefore each of the 100 catalogs is possibly the correct observed data, and each has an individual interevent distribution. For every lower magnitude threshold between $M \geq 8.3$ and $M \geq 8.7$, there are thus 100 realizations of the observed catalogs, and for each of those, we tally up how many of 1000 synthetic catalogs have the same number of intervals in one-year bins. We give the means of these results and the ranges across 95% of the calculated number of matches in Figure 6.

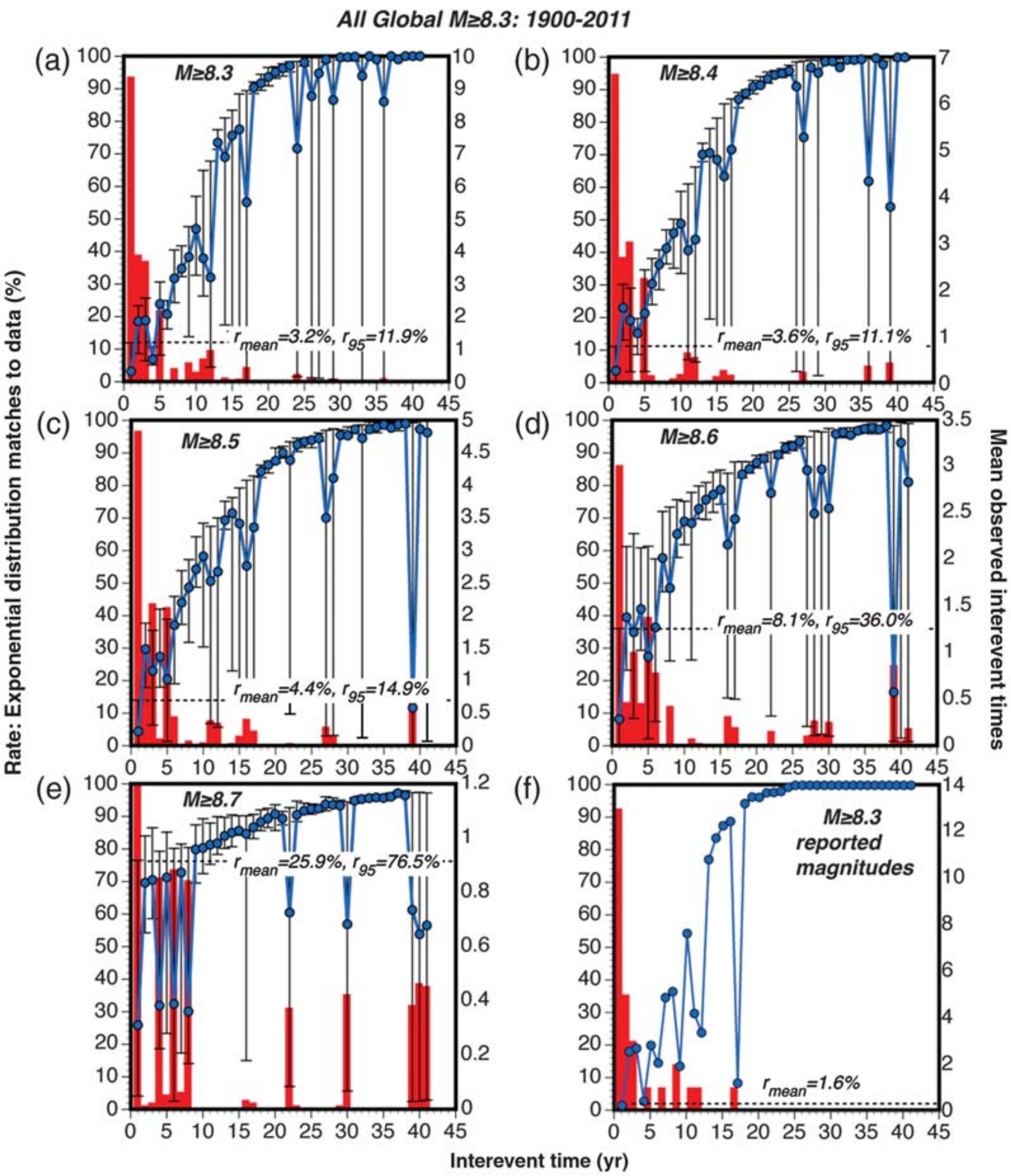

Figure 6. (a) The blue curves show calculated rates (in % of 1000 synthetic catalogs) that the number of time intervals observed between $M \geq 8.3$ earthquakes is matched by a Poisson process (left vertical axis). The red columns show mean observed interevent distributions (right vertical axis). (b–e) The same calculations as in (a) but for higher magnitude cutoffs. The error bars give the effects of the small observed sample (found from 1000 simulations) and magnitude uncertainty (100 draws from distributions like those shown in Fig. 4). (f) The same analysis is performed assuming that reported magnitudes are exactly correct. As expected (Fig. 5), the lowest rates are found for the shortest intervals (< 1 yr) in all cases (values are shown by the horizontal dashed lines).

Generation of synthetic catalogs using Monte Carlo sampling of exponential distributions accounts for the expected variability because of the small number (31) of global $M \geq 8.3$ earthquakes (Fig. 2). We treat the period between 1900 and the first event of a given magnitude cutoff after 1900 as an additional interval, which is likely shorter than the actual duration. However, we want to include this interval because information can be conveyed by a long observed gap between 1900 and the first event above a given magnitude cutoff. There is no corresponding interval at the end of the catalog because of the 2011 M 9.0 Tohoku earthquake. Each distribution mean used to make synthetic catalogs is adjusted to equal the number of intervals for each of the 100 potentially observed catalogs (as described previously) and can have different numbers of events because of magnitude variation. This process yields a total of 100,000 simulations for each cutoff magnitude studied ($M \geq 8.3$ to $M \geq 8.7$ in 0.1 magnitude units).

The error bars on Figure 6 combine the effects of sampling interevent times and magnitudes because each of 1000 draws is compared with one of 100 realizations of the possible event magnitudes. For all magnitude cutoffs we examine between $M \geq 8.3$ and $M \geq 8.7$, we note that the lowest match rate between observations and synthetic catalogs is for interevent times of <1 yr (Fig. 6), with mean values ranging from 3.2% for $M \geq 8.3$ to 25.9% for $M \geq 8.7$. Therefore, the feature that appears least likely when compared with a Poisson process is the occurrence of so many earthquakes (~9 on average) with short ($t < 1$ yr) interevent periods that are present in the global $M \geq 8.3$ catalog (Fig. 6). However, as can be seen in Figure 5, the 0–1 yr interevent time bin has the smallest chance (~11%) of being repeated generally if a Poisson process is active.

We note the thresholds where 95% of the random draws from exponential distributions are found (error bars and r_{95} values given in Figure 6). We therefore take the high end of these ranges to be the points of maximum compatibility of a random-in-time model with the observations and the low end to be the minimum. Under these criteria, we interpret the shortest interevent times of $M \geq 8.3$ earthquakes as having up to an 11.9% rate of matching a random process. This interpretation changes as a function of interevent time. Long quiescent periods in the global catalog (up to 36 yr for $M \geq 8.3$) do not preclude a Poisson process in any of our calculations. For example, in the $M \geq 8.3$ catalog, we note a broad range of match rates between 0% and 100% of the 1000 synthetic catalogs with the longest observed interevent time being 36 yr, with a mean over the calculations of 86.0% (Fig. 6). One could turn this argument around and point out that the low thresholds on probability that specific

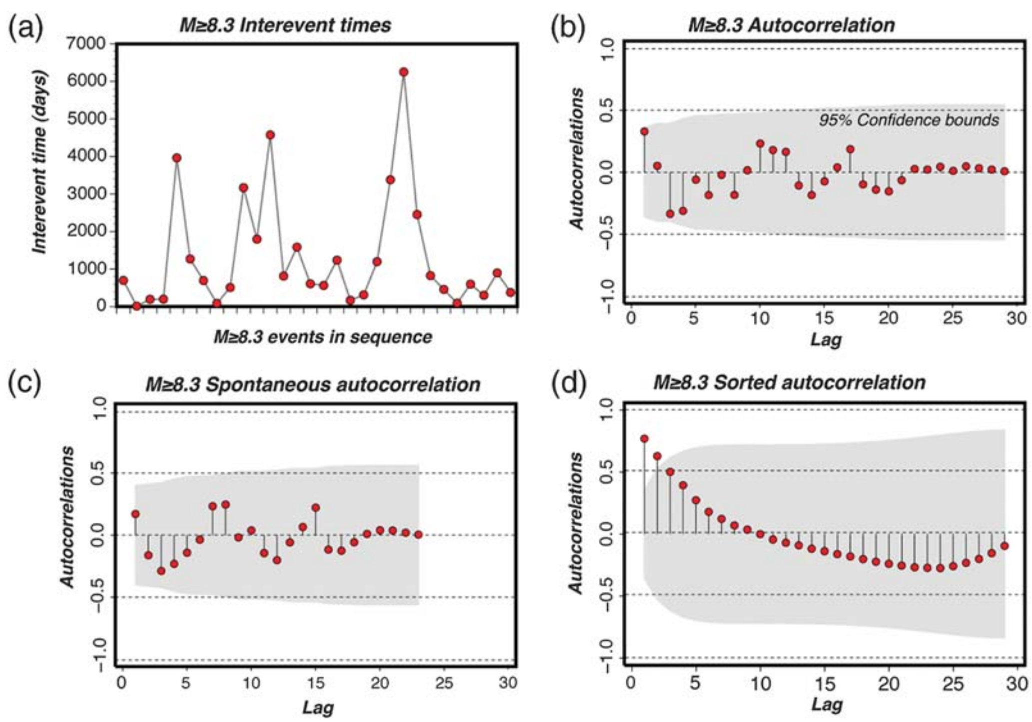

Figure 7. Autocorrelation test of observed $M \geq 8.3$ interevent times. (a) Events in sequence are shown as a function of the number of days separating them. (b) Interevent times are autocorrelated; that is, the trace of (a) is compared with itself to see if there is any periodicity or dependence between interevent times. The lag gives the interevent time in sequence that is being compared. When (b) all events are studied, or (c) spontaneous events are studied, there is no significant (at 95% confidence) dependence among the observed intervals. When (d) intervals are artificially sorted from least to greatest, then dependence is evident in the autocorrelations. This is done to show the efficacy of the test.

intervals came from an exponential distribution can be 0% (Fig. 6), meaning that the null hypothesis could be false.

Test of the Independence of Interevent Times

A Poisson process is defined as one in which independent events are separated by exponentially distributed timing. We are unable to rule out an exponential distribution underlying global $M \geq 8.3$ earthquake interevent times, but that alone does not establish whether there is (or is not) temporal dependence among them. In a Poisson process, the amount of time since the last event contains no information about the amount of time until the next event. One test to determine if such dependence is present is an autocorrelation on sequential earthquake intervals. This process tests for functional dependence by identifying repeating or periodic patterns within the interevent distribution.

We conducted autocorrelations on the observed $M \geq 8.3$ catalogs to see if there is any significant dependence but were unable to find any values that exceeded the 95% confidence bounds (Fig. 7). Confidence bounds were calculated using the formula derived by Bartlett (1946) for variance, where $\mathrm{var} = \frac{1}{n}\left[1 + 2\sum_{i=1}^{v-1}\rho^2(i)\right]$, n is the number of intervals, and $\rho(i)$ is autocorrelation values for given lags (v) (e.g., Brockwell and Davis, 2002). For comparison purposes, we sorted the observed interevent times from shortest to longest to create the appearance of a functional dependence between them and ran an autocorrelation test (Fig. 7d). In

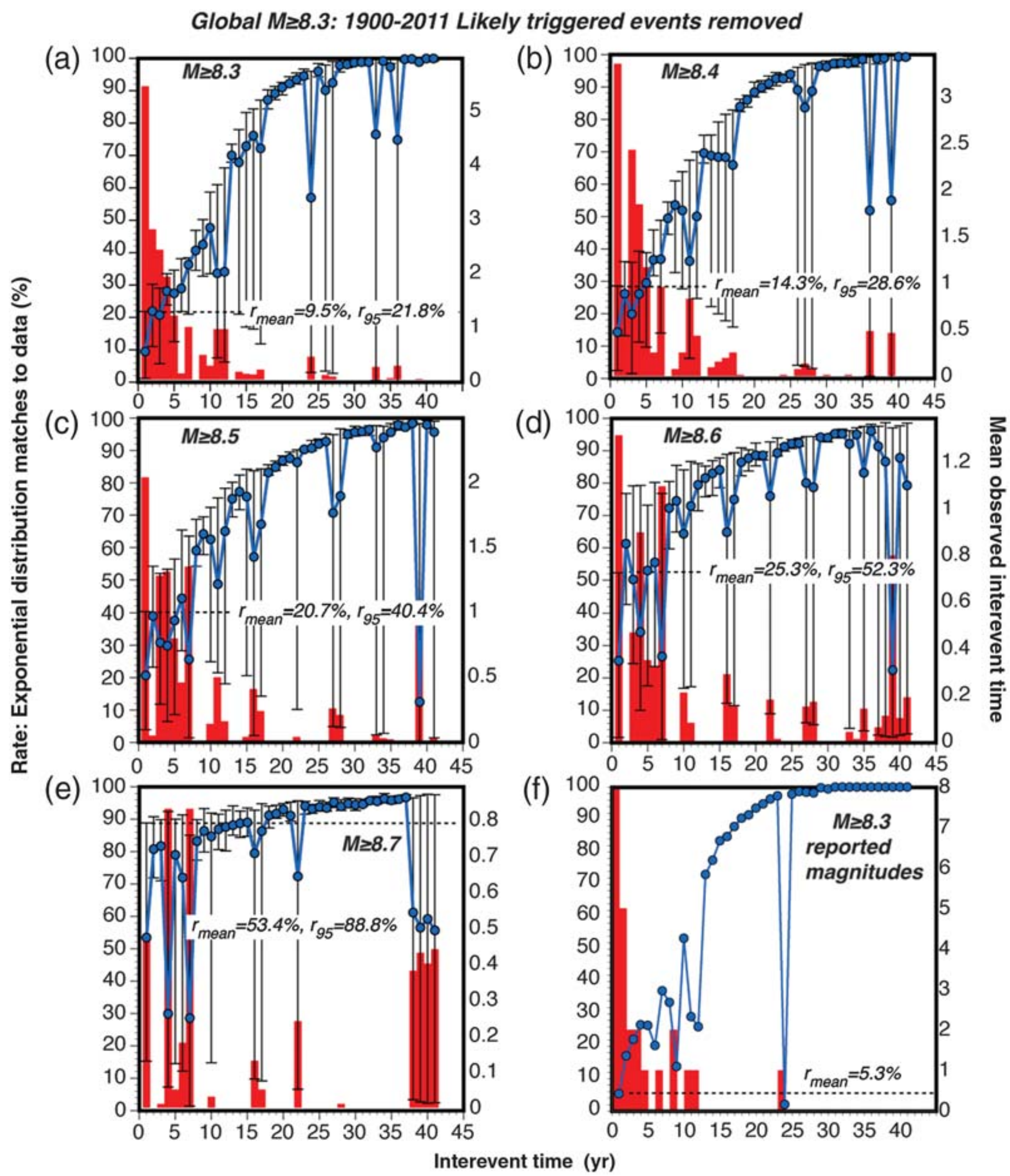

Figure 8. (a–f) The same information is presented as in Figure 6 except the input catalog has the likely triggered events identified in Figure 2 removed.

that case, we do note significant correlations over the first two lags, as would be expected.

Analysis with Local Aftershocks Removed

We want to assess whether global $M \geq 8.3$ earthquake occurrence is independent and random in time. A clear temporal dependence between mainshock earthquakes and aftershocks has been demonstrated (e.g., Omori, 1894; Ogata, 1998), and a number of physical models for this dependence have been identified. For example, there are stress-change explanations of short-term links among earthquakes, particularly those that are near in space (Yamashina, 1978; Das and Scholz, 1981; Stein and Lisowski, 1983; King *et al.*, 1994; Freed, 2005) and possibly at global distances as well (Hill *et al.*, 1993; Gomberg *et al.*, 2004; Hill, 2008), though this has been difficult to establish for larger earthquakes (Parsons and Velasco, 2011). Therefore, if we want to make comparisons between observed catalogs and synthetic ones created assuming a Poisson process, then events with close temporal and spatial associations that are explicable by vetted physical models should be excluded.

We repeat the calculations made on the $M \geq 8.3$ catalog shown in Figure 6 with a new catalog comprised of spontaneous earthquakes (a list of removed events is given in Table 2). The removal of likely aftershocks reduces the number of short intervals in the catalog. As a result, we calculate the shortest interevent times of $M \geq 8.3$ earthquakes as having a mean matching rate of 9.5% to synthetic catalogs and a maximum rate of 21.8% (Fig. 8). This result implies that if global earthquakes are randomly distributed, short-term clustering in the 111-yr $M \geq 8.3$ catalog of spontaneous earthquakes is comparable to the expected ~11% repeat rate from synthetic catalogs (Fig. 5). This again points out that any specific outcome is unlikely, and that the past decade of apparently increased rates of great earthquakes is not necessarily anomalous. Matching rates from the Poisson model for short interevent times are higher for all tested magnitude thresholds when using the spontaneous catalog (Fig. 8) than when all events are included (Fig. 6).

Conclusions

We find, as did Michael (2011), that the interevent distribution of great earthquakes over the past 111 yr, when examined as a whole, cannot be excluded as having emerged from a random-in-time Poisson process at 95% confidence. Neither can they be excluded as having come from distributions representing time dependence or cluster-type models (Fig. 3).

We study the specifics of the apparent clustering behavior of the catalog that has captured scientific and public attention by breaking up the interevent distribution into one-year bins. This enables us to assess features like short-term clusters of events and intervening periods of quiescence. We find that the number of shortest $M \geq 8.3$ earthquake intervals (< 1 yr) over the past 111 yr is matched by a small number of synthetic catalogs, with mean values ranging from 3.2% for $M \geq 8.3$ to 25.9% for $M \geq 8.7$ (Fig. 6). When we study a catalog with likely triggered events removed, we find mean values ranging from 9.5% for $M \geq 8.3$ to 53.4% for $M \geq 8.7$ (Fig. 8).

Observed earthquake intervals seem increasingly compatible with a random-in-time distribution when higher magnitude cutoffs are imposed, or when longer interevent times are considered. However, the results of examining specific features of the interevent distribution should be interpreted in the context that if global great earthquakes are occurring at random then any specific number of events that happen in a short time is unlikely to be repeated in a similar way in an ~100-yr span. We conduct an experiment with the parameters of the observed catalog of $M \geq 8.3$ events to find the probability of repeating a given number of intervals that fall into one-year bins and find that the lowest value is for 0–1-yr interevent times at 11.1% (Fig. 5). This is a natural feature of the exponential distribution, which has more weight at small times. There is thus a larger range of possible integer values in the small-time bins, and the rate of repeating

Table 1
Catalog of $M \geq 8.3$ Earthquakes Used in This Study

Date (dd/mm/yyyy)	Latitude	Longitude	Z (km)	M_w
11/08/1903	36.3600	22.9700	80.0	8.3
09/07/1905	49.0000	99.0000	0.0	8.5
23/07/1905	49.0000	98.0000	0.0	8.4
31/01/1906	1.0000	−81.5000	0.0	8.6
17/08/1906	−33.0000	−72.0000	0.0	8.5
26/06/1917	−15.5000	−173.0000	0.0	8.5
16/12/1920	36.6010	105.3170	25.0	8.3
11/11/1922	−28.5530	−70.7550	35.0	8.7
03/02/1923	53.8530	160.7610	35.0	8.5
26/06/1924	−56.4070	158.4890	15.0	8.3
02/03/1933	39.2240	144.6220	35.0	8.4
01/02/1938	−5.0500	131.6200	35.0	8.4
15/08/1950	28.5000	96.5000	0.0	8.6
04/11/1952	52.7500	159.5000	0.0	9.0
09/03/1957	51.5870	−175.4190	35.0	8.6
06/11/1958	44.3110	148.6500	35.0	8.4
22/05/1960	−38.2940	−73.0540	35.0	9.6
13/10/1963	44.7630	149.8010	26.0	8.6
28/03/1964	61.0190	−147.6260	6.3	9.2
04/02/1965	51.2100	178.4980	28.8	8.7
16/05/1968	40.9010	143.3460	26.0	8.3
19/08/1977	−11.1250	118.3800	20.9	8.3
04/10/1994	43.8320	147.3320	33.3	8.3
23/06/2001	−16.265	−73.641	33	8.4
25/09/2003	41.815	143.91	27	8.3
26/12/2004	3.295	95.982	30	9
28/03/2005	2.085	97.108	30	8.6
15/11/2006	46.592	153.266	10	8.3
12/09/2007	−4.438	101.367	34	8.5
27/02/2010	−36.122	−72.898	22.9	8.8
11/03/2011	38.297	142.373	29	9.1

The catalog is from Engdahl and Villaseñor (2002), augmented for the period 2000–2011 with the ANSS catalog. All event sizes are given as moment magnitudes.

Table 2
Catalog of $M \geq 8.3$ Earthquakes with Likely Aftershocks/Triggered Earthquakes Removed

Region	Date (dd/mm/yyyy)	Latitude	Longitude	Range (km)	Depth (km)	M_w	Reference
Mongolia	**09/07/1905**	**49.0**	**99.0**		**0.0**	**8.5**	Chery *et al.* (2001)
	23/07/1905	49.0	98.0	111.2	0.0	8.4	
Kamchatka	**03/02/1923**	**53.853**	**160.761**		**35.0**	**8.5**	Ruppert *et al.* (2007)
	04/11/1952	52.75	159.50	248.6	0.0	9.0	
Kuriles	**06/11/1958**	**44.311**	**148.650**		**35.0**	**8.4**	Parsons (2002)
	13/10/1963	44.763	149.801	146.1	26.0	8.6	
	04/10/1994	43.832	147.332	164.2, 310.2	33.3	8.3	
Chile	**22/05/1960**	**−38.294**	**−73.054**		**35.0**	**9.6**	Stein *et al.* (2010)
	27/02/2010	−36.122	−72.898	303.7	22.9	8.8	
Sumatra	**26/12/2004**	**3.295**	**95.982**		**30.0**	**9.0**	Nalbant *et al.* (2005)
	28/03/2005	2.085	97.108	134.7	30.0	8.6	

The events in bold-face type are mainshocks, and others are treated as aftershocks.

any given value decreases. Thus, features in the observed catalog seem unusual at first glance but are in fact quite expected from a random-in-time Poisson process.

So, were global $M \geq 8.3$ earthquake time intervals random between 1900 and 2011? Our results do not disprove a physical link that causes global earthquake clusters, but they show that the past 111-yr pattern of $M \geq 8.3$ earthquakes does not require one. We find no evidence that the features of great-earthquake occurrence are inconsistent with a random-in-time, Poisson process.

Data and Resources

Earthquake catalogs used in this study to were drawn from the Centenial Catalog of Engdahl and Villaseñor, (2002) for the period 1900–1999 and augmented for the period 2000–2011 through the ANSS catalog search linked through the Northern California Earthquake Data Center (NCEDC) web site at http://www.ncedc.org/anss/catalog-search.html (last accessed November 2011).

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